INTENSITY DISTRIBUTION IN THE OSCILLATING TURBULENT BOUNDRY LAYER ON A FLAT PLATE

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ABSTRACT

The effect of oscillating flow on the turbulent intensity distribution in the turbulent boundary layer on a flat plate was investigated experimentally.

A wind tunnel incorporating a set of rotating shutter blades downstream of the test section was used to create oscillating flow with amplitude variations from 6 to 110 per cent of mean velocity and frequencies ranging from 5 to 80 cycles per second at a local Reynolds number of 1.5×10^6. A vertical traverse of the turbulent boundary layer was conducted with a hot wire anemometer, and the mean velocity profile and the turbulent intensity distribution were recorded.

Results indicate that there is no radical effect on the turbulent intensity distribution in the boundary layer due to frequency or amplitude changes in the oscillating freestream flow.

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LIST OF SYMBOLS

Symbol	Definition	Units
f	Frequency of Freestream Velocity Fluctuations	cps
δ	Boundary Layer Thickness	inches
y	Vertical Displacement from Surface	inches
ν	Kinematic Viscosity	ft^2/sec
x	Length Coordinate	feet
p	Mean Static Pressure	cm H_2O
p_o	Mean Static Pressure at Test Point	cm H_2O
q	Reference Dynamic Pressure	cm H_2O
$\bar{u}$	Local Mean Velocity	ft/sec
U_{fs}	Mean Freestream Velocity	ft/sec
ΔU	Velocity Fluctuation Amplitude	ft/sec
R_x	Local Reynolds Number $= \frac{U_{fs}\, x}{\nu}$	
I	Turbulent Intensity (local)	
I_{fs}	Freestream Turbulent Intensity	
N_f	Normalized Frequency Parameter $= \frac{f\,\nu}{U_{fs}^2}$	
N_i	Normalized Turbulent Intensity $= \frac{I}{I_{fs}}$	
N_a	Normalized Velocity Fluctuation Amplitude $= \frac{\Delta U}{U_{fs}}$	

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1. Introduction

Although the unsteady turbulent boundary layer is a common phenomenon, very little work has been done to better the understanding of this complex problem. The steady turbulent boundary layer is a non-linear mechanism, and when this situation is further complicated by a time-dependent mean freestream velocity, a full analytical solution is a formidable task.

Karlsson (ref. 1) investigated the nonsteady turbulent boundary layer by separating the velocity fluctuations into periodic and random components. By averaging the oscillations over a complete period and substituting the results into the equations of motion, he obtained equations similar to the steady turbulent boundary layer equations with an extra fluctuating term. He predicted and experimentally verified that the oscillations had little effect on the mean velocity profile in the turbulent boundary layer.

Klebanoff (ref. 2) has recorded the distribution of turbulent intensity in the turbulent boundary layer on a flat plate immersed in a steady flow of very low freestream turbulence. A similar study has also been conducted by Reichardt (ref. 9).

Morrissey (ref. 5) has investigated the effects of large amplitude flow oscillations on the heat transfer rates from a flat plate. His results indicate no measurable influence on local heat transfer rates from the superposition of large amplitude fluctuations on the turbulent boundary layer. These results would suggest that the eddy diffusivity and thus the turbulent intensity distribution should exhibit similar behavior.

The objective of the present work is to investigate experimentally the effect of an oscillating mean stream on the turbulent intensity distribution in the fully established turbulent boundary layer.

2. Experimental Equipment and Procedure

2.1 The Wind Tunnel

2.1.1 General Description

The oscillating flow wind tunnel in the Aeronautics Department Laboratories of the Naval Postgraduate School was used for this investigation. This is an open circuit tunnel with a test section 24 inches square and 223 inches long. The tunnel is of metal and Lucite construction. The inlet section shown in Figure 1 has a contraction ratio of 16:1, which, coupled with three high solidity screens, results in very low freestream turbulent intensities. Measured steady free-stream turbulence levels in the test section varied from 0.25 to 0.37 per cent of the freestream velocity.

The wind tunnel is driven by two 100 horsepower Joy Axivane fans with adjustable blades. Located in front of each fan is a set of variable inlet vanes which serve as controls for the velocity in the test section. To reduce velocity the vanes pre-swirl the air in the direction of fan rotation, reducing the fan work input. The pitch of the fan blades was set to produce velocities of 88 to 250 feet per second. The mean test section velocity was measured with a pitot-static tube and an inclined draft gauge.

2.1.2 The Rotating Shutter Valve

A shutter valve was used to superimpose an oscillating sinusoidal component onto the mean freestream velocity. It consists of four rotating blades driven by a variable speed motor. Figure 2 shows the shutter valve with 5-inch blades installed. The motor speed and pulley ratio selection determine the frequency of oscillation, and the blade width (and to some extent the frequency) determine the

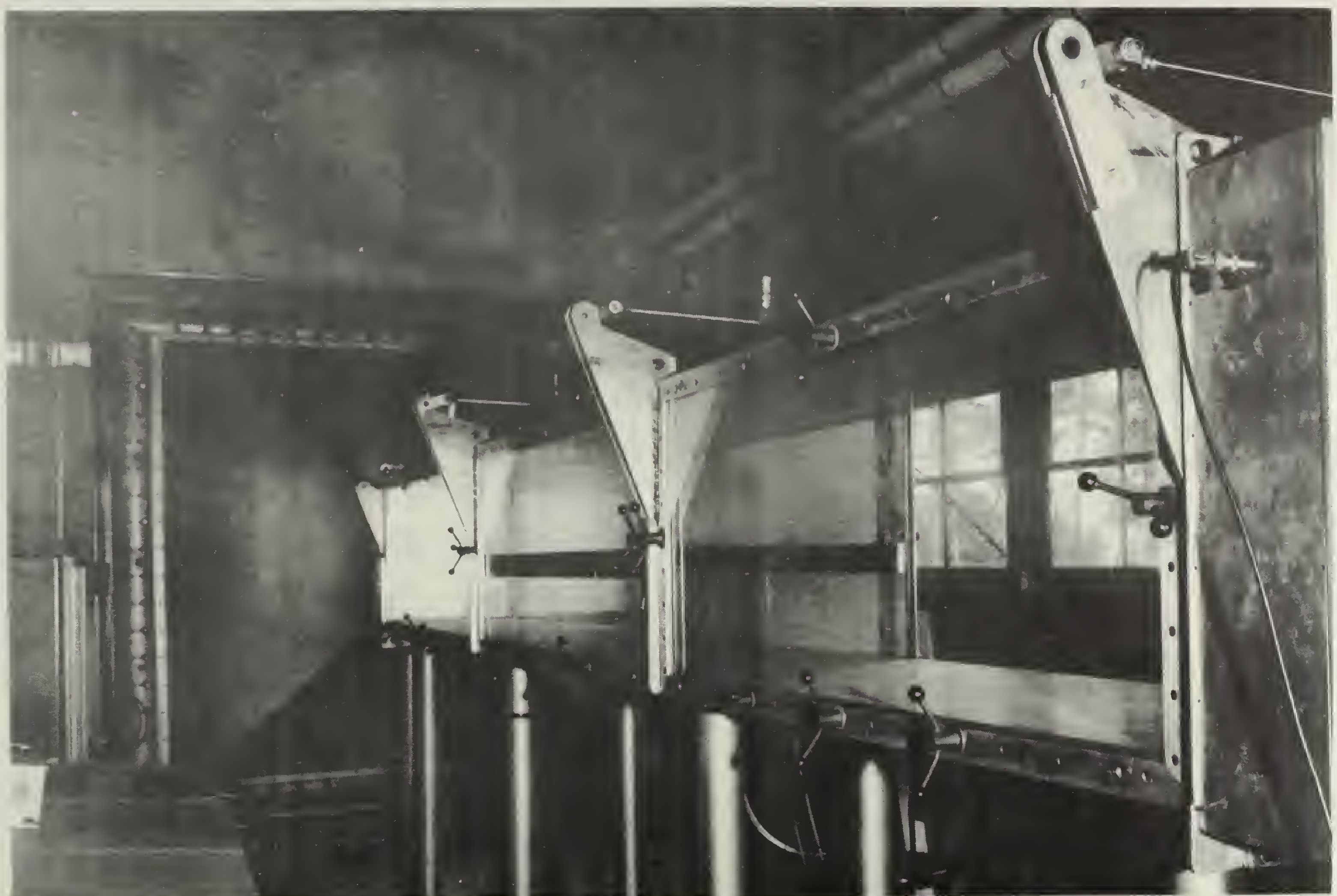

FIGURE I

INLET AND TEST SECTIONS

FIGURE 2

ROTATING SHUTTER VALVE

amplitude. For the present work a range of frequencies from 5 to 80 cycles per second and amplitudes from 6 to 110 per cent of the freestream velocity was produced by employing three blade widths and two pulley ratios.

2.1.3 The Test Section

The test section is constructed of 2-inch thick aluminum plates on top and bottom and 2-inch thick stress-relieved Lucite on the sides. One back panel of Lucite has been replaced with wood for convenience in mounting the model and instrumentation. Figure 3 is a photograph of the test section with the side panels raised.

2.2 The Model

The flat plate model was constructed of a slab of phenolic material 24 inches wide, 55 inches long and 5/8 inch thick. It was provided with a rounded leading edge in order to avoid leading edge separation. A 5-inch tapered spoiler which could be adjusted from outside the tunnel was used to trim the pressure gradient. The model and spoiler are shown in Figure 4. The traversing mechanism was attached to the underside of the plate, and the probe was extended up through the plate and bent forward and down to the upper surface at a point 27 inches aft of the leading edge. The traversing mechanism was designed to be mounted on the model rather than on the tunnel test section in order to avoid vibration problems produced by the oscillating stream. The traverse mechanism, shown in Figure 5, provided a resolution of 0.001 inch in displacement, measured with a dial indicator.

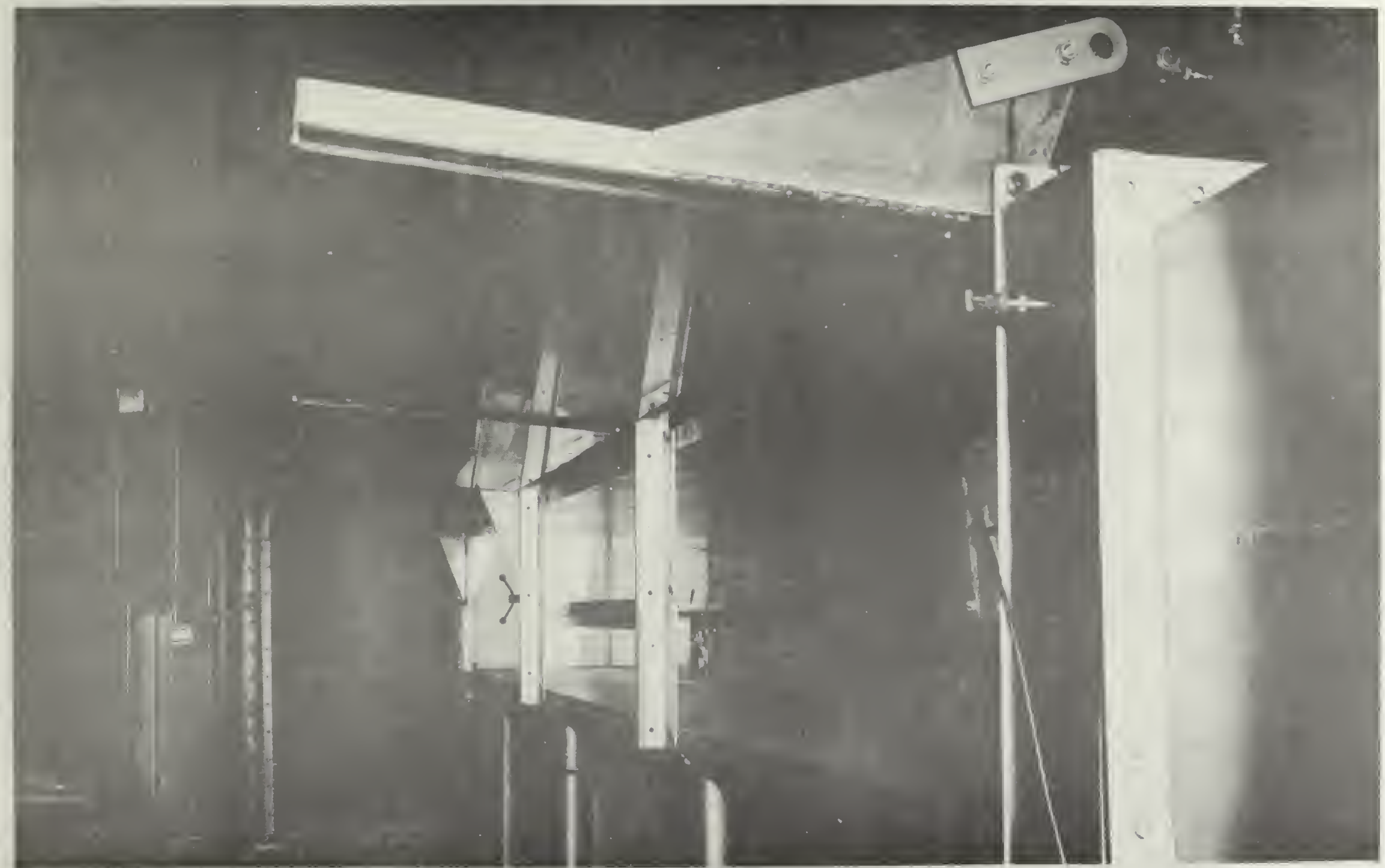

FIGURE 3

TUNNEL TEST SECTION

FIGURE 4
FLAT PLATE MODEL

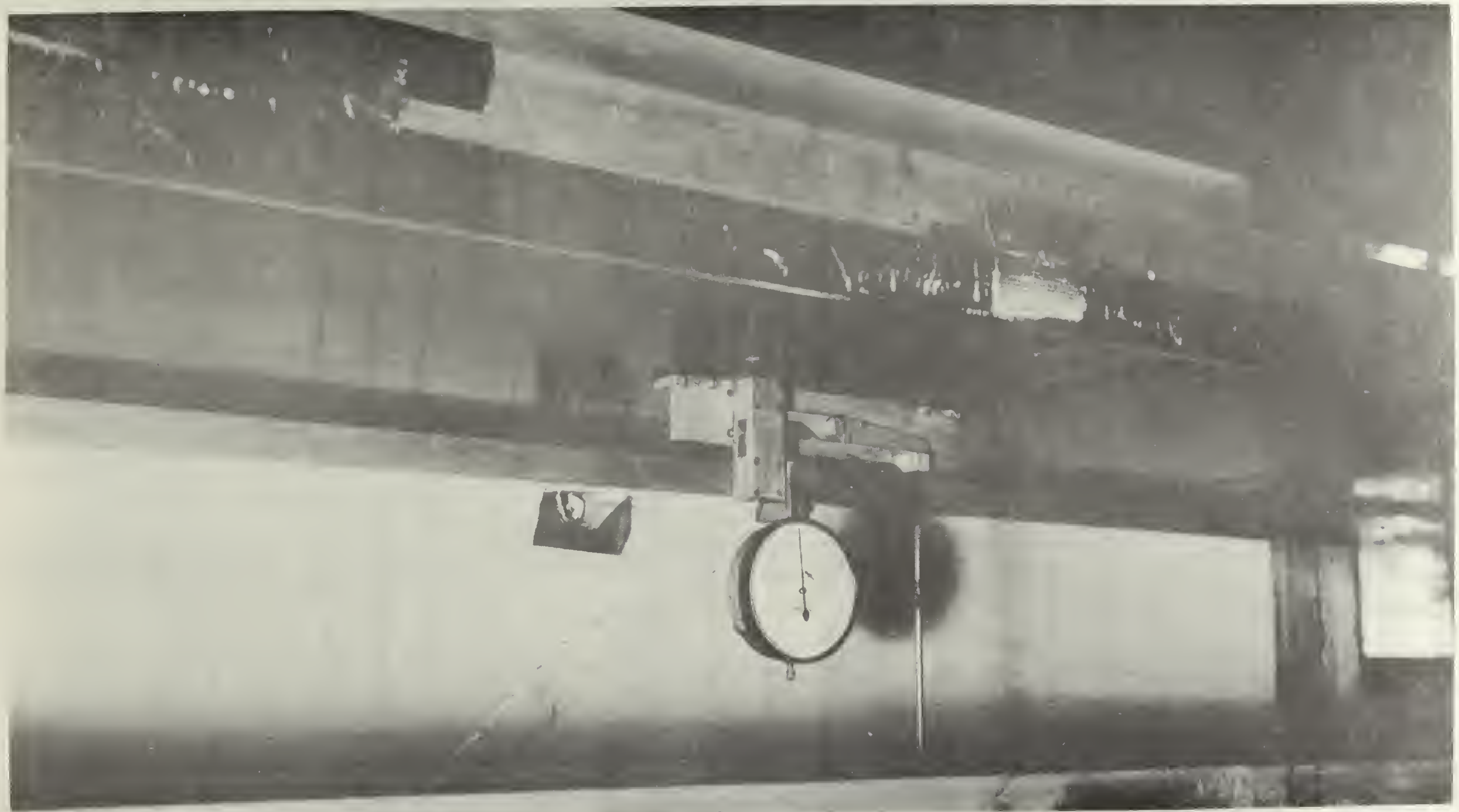

FIGURE 5

TRAVERSE MECHANISM

2.3 Instrumentation

A transistorized, ten channel, constant temperature hot wire anemometer was employed in this work (Security Associates Model 1000). This equipment is shown in Figure 6. The hot wire consisted of a 0.00015 inch diameter and 0.080 inch long tungsten filament. The hot wire circuit contains a built-in analog computer which produces an output which is linear in velocity. Since the circuitry is D.C. coupled, the total instantaneous velocity is available at the output. Calibration of the apparatus was performed similar to the method used by Murphy (ref. 6). The turbulent intensity was measured with a Ballentine True RMS Voltmeter. An oscilloscope trace of the velocity wave form was recorded photographically.

The frequency of oscillation was determined by a magnetic pickup mounted outboard of the upper shutter valve blade shaft. The output pulse frequency was read on a Berkeley decade counter. The instrumentation system is shown pictorially in Figure 7 and schematically in Figure 8.

2.4 Procedure

After the plate was installed in the test section and adjusted to zero incidence, a static pressure survey was made to ensure the existence of a zero pressure gradient. Results of the pressure survey are shown in Figure 9. Next, conditions necessary for a fully established turbulent boundary layer were determined. A hot wire probe with tips bent down close to the surface well into the boundary was used to traverse the plate in a longitudinal direction. This device, shown in Figure 10, provided an indication of the transition point and the turbulent intensity along the plate at a constant vertical displacement of about 0.020 inch.

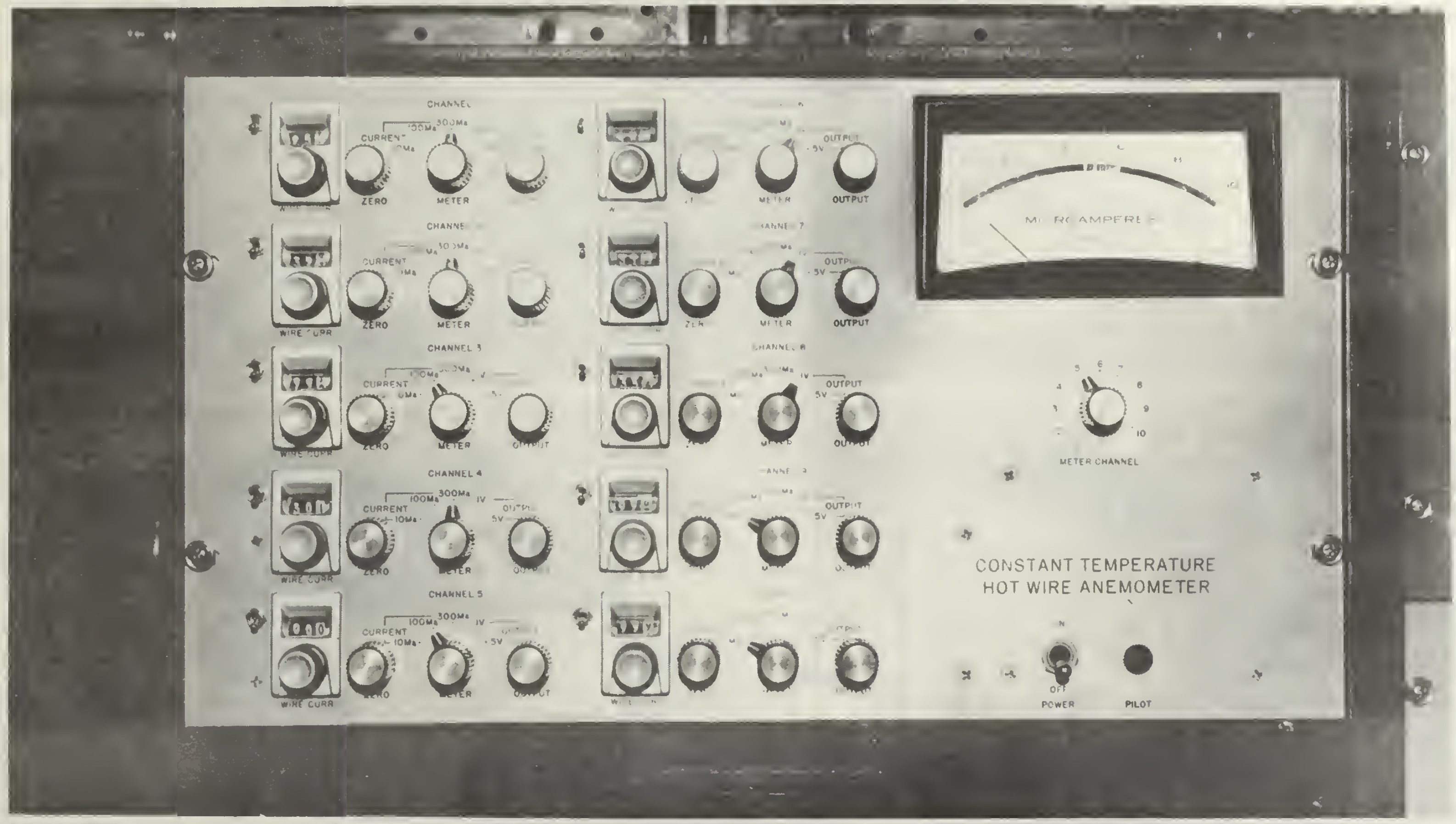

FIGURE 6

HOT WIRE ANEMOMETER

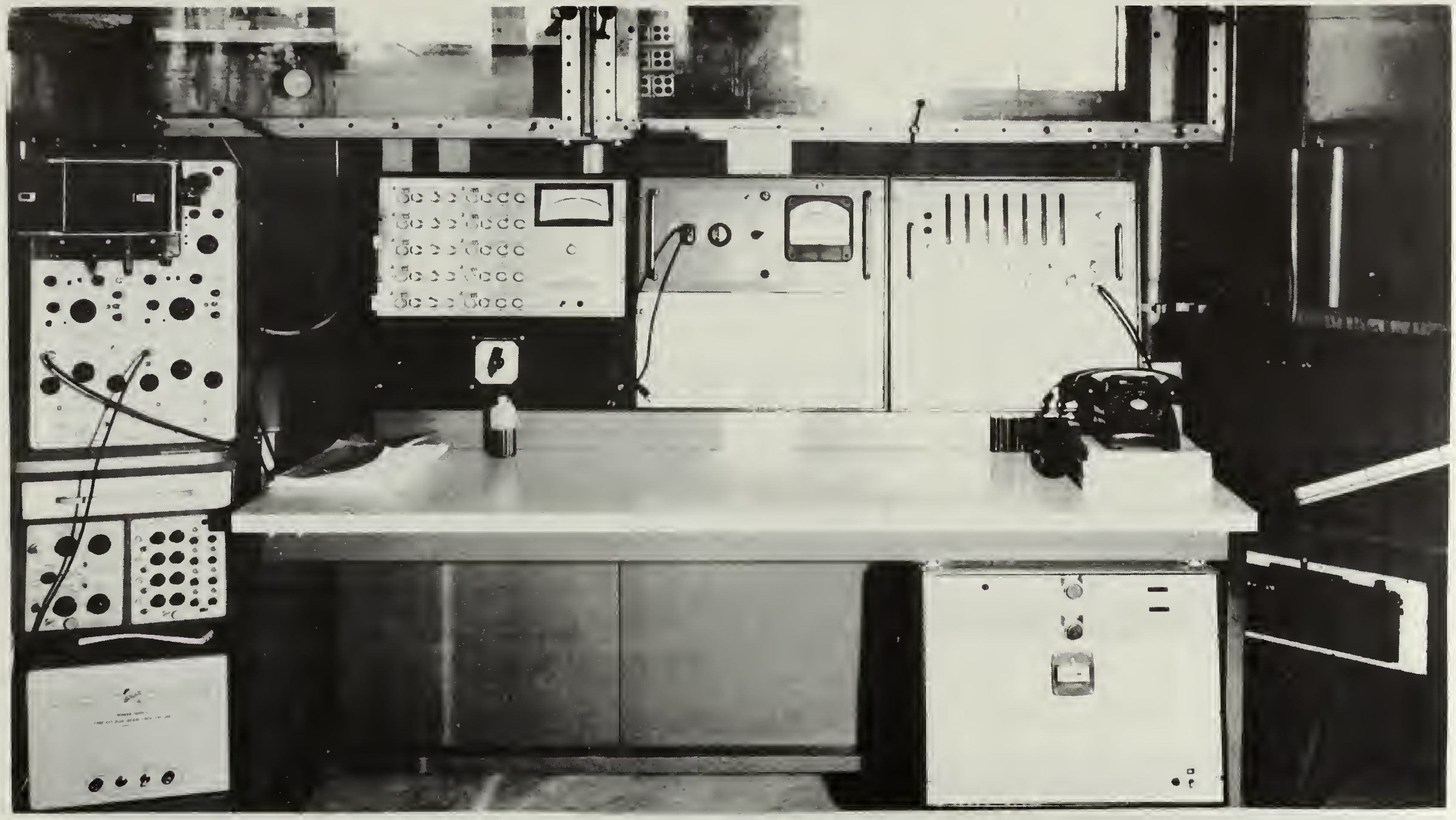

FIGURE 7

INSTRUMENTATION AND CONTROL EQUIPMENT

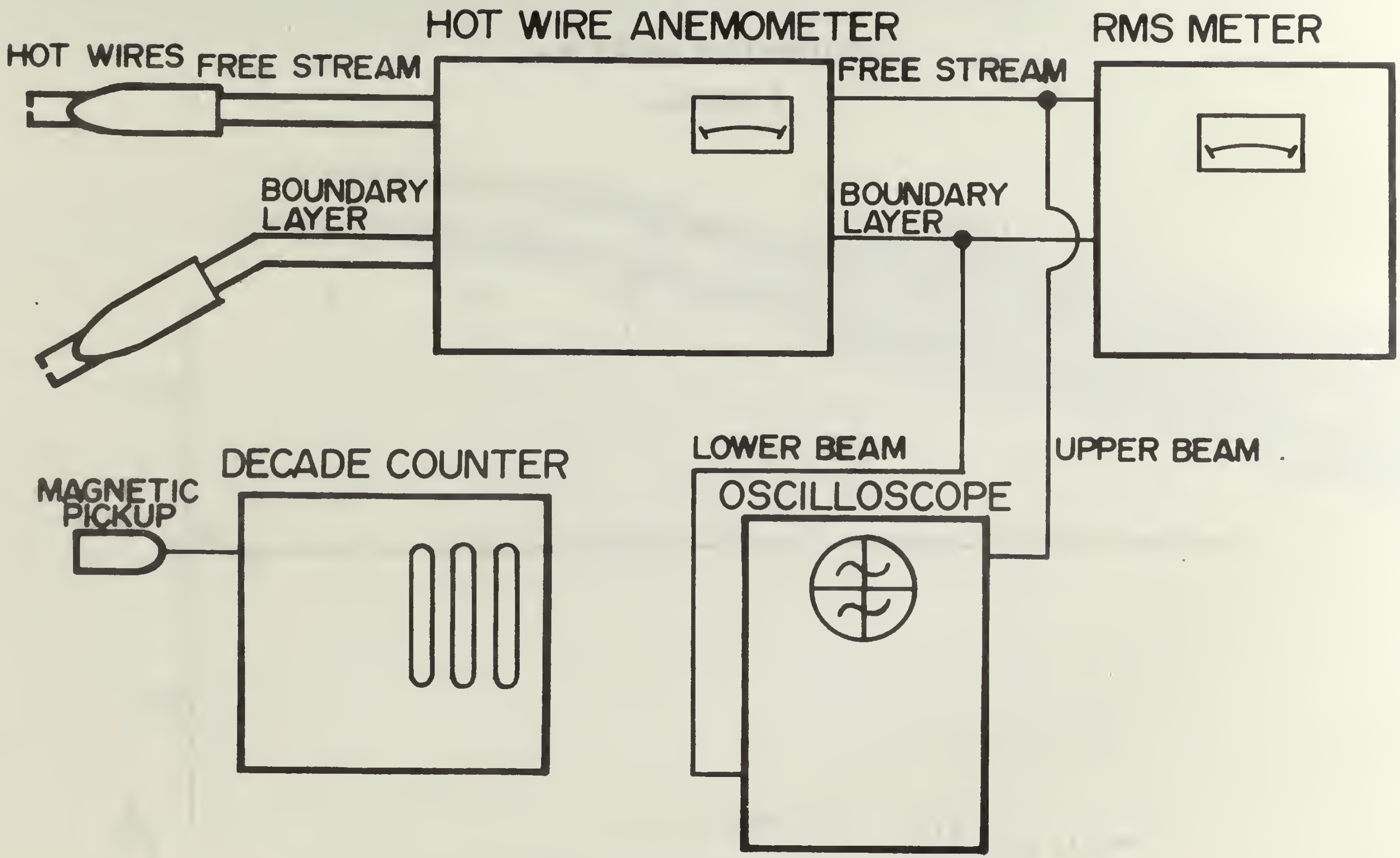

FIGURE 8

SCHEMATIC DIAGRAM OF INSTRUMENTATION

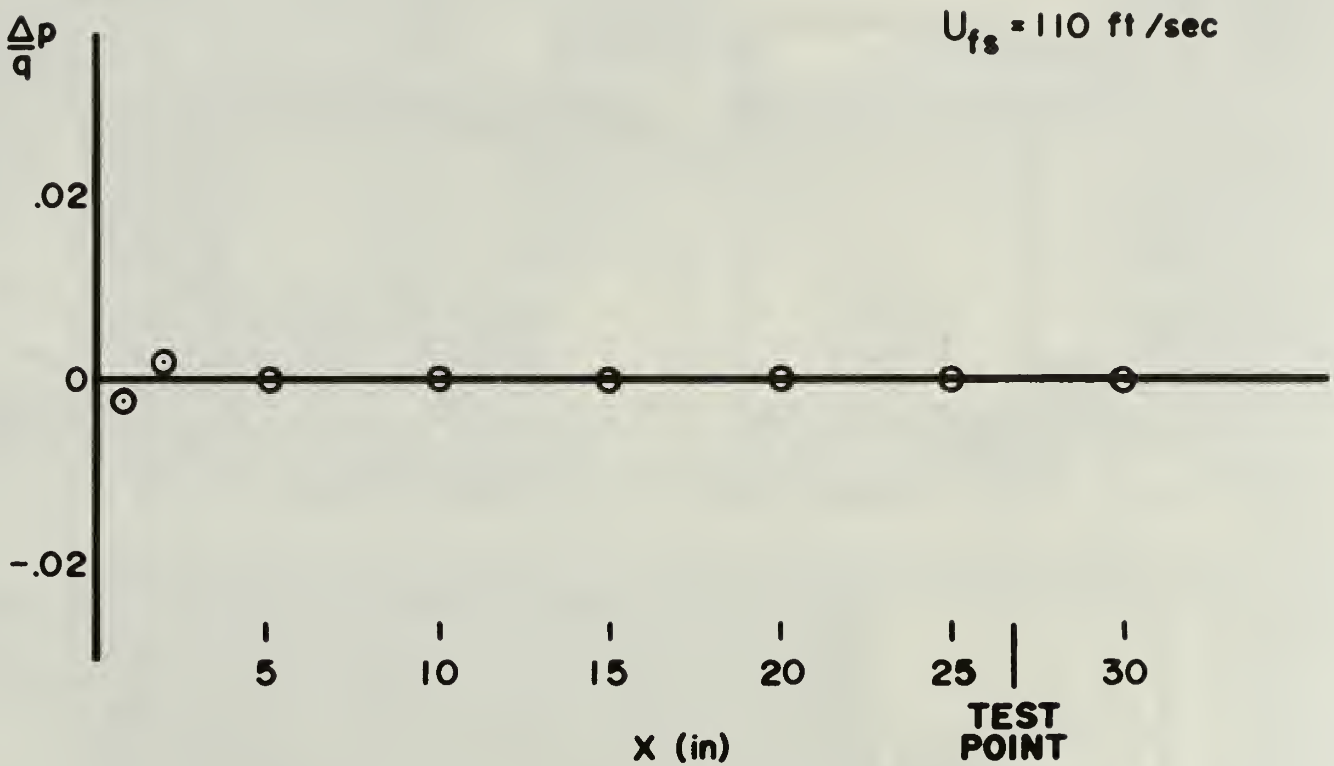

FIGURE 9

PRESSURE DISTRIBUTION

FIGURE 10

LONGITUDINAL TEST PROBE.

A test section velocity of 110 feet per second was found to cause transition 17 inches from the leading edge and lead to a fully established turbulent boundary layer at the test point, 27 inches from the leading edge ($R_x = 1.5 \times 10^6$). The results of this preliminary investigation are summarized in Table I.

For each experimental run the boundary layer thickness was determined, and a vertical traverse of the boundary layer was then conducted, during which the mean velocity and the turbulent intensity were recorded.

TABLE I

TRANSITION DATA

U_{fs}	x (in)	$R_x \times 10^{-6}$	Regime
100	10	0.529	Laminar
	12	.635	Laminar
	16	.846	Laminar
	18	.970	Near Transition
	19	1.020	Transition
105	13	.725	Laminar
	15	.837	Laminar
	18	1.000	Transition
	20	1.120	Turbulent
110	15	.875	Laminar
	16	.935	Laminar
	17	1.000	Transition
	18	1.050	Turbulent
	27	1.576	Turbulent (Test Position)

Photographs of the oscilloscope traces were taken at various positions during the vertical traverse of the boundary layer. Oscillation frequencies of 5, 10, 20, 40, and 80 cycles per second were investigated for each of three sets of blade widths (2-inch, 3-inch, and 5-inch) corresponding to fluctuation amplitudes of 6 to 110 per cent of the mean freestream velocity. A summary of the experimental operating conditions and normalized frequency and amplitude parameters is presented in Table II.

TABLE II

EXPERIMENTAL OPERATING CONDITIONS

Mean Velocity: 110 ft/sec   Local Reynolds Number: 1.57×10^6

Run	Blade Width (in)	Frequency (cps)	$N_f \times 10^8$	N_a	Freestream Turbulent Intensity (% U_{fs})
1	2	5	6.5	0.07	2.0
2	2	10	13.0	.08	2.0
3	2	20	26.0	.07	2.1
4	2	40	52.0	.06	2.0
5	2	80	104.0	.06	1.5
6	3	80	104.0	.16	4.5
7	3	40	52.0	.16	6.7
8	3	20	26.0	.24	6.3
9	3	10	13.0	.16	4.6
10	3	5	6.5	.20	5.5
11	5	5	6.5	1.10	25.0
12	5	10	13.0	.95	21.0
13	5	20	26.0	.60	20.5
14	5	40	52.0	.60	18.8
15	5	80	104.0	0.60	19.8

3. Experimental Results and Discussion

The experimental results are presented in Table III (Appendix). Figures 11, 12, and 13 summarize the effect of frequency on the turbulent intensity distribution in the oscillating turbulent boundary layer for each of the three amplitude ranges investigated. Also included in these graphs are typical velocity profiles for each of the amplitude ratios. The results are presented as the ratio of local intensity to freestream intensity (N_i) because the freestream magnitude is clearly a determining factor on the intensity magnitude in the boundary layer. This normalized turbulent intensity appears relatively independent of frequency for each amplitude range.

Curves for the mean intensity distributions for each of the amplitudes are compared with the steady flow results of Klebanoff (ref. 2) and Reichardt (ref. 9) in Figure 14. A check of steady flow results was in close agreement with those of Klebanoff. Although there is a slight trend toward decreasing turbulent intensity with increasing oscillation amplitude, the general shape of the curve is clearly preserved. In each case the pronounced maximum is in close proximity to the wall. Moreover, there are no radical differences between the distribution results measured in oscillating flows and those measured in steady flow. One would assume such differences small when comparing flows with freestream turbulence intensity levels ranging from 0.20 to 25.0 per cent. Moreover, the data indicate that relative intensity is essentially unaltered very close to the surface, which is the primary region of importance in determining heat transfer rates. With some degree of certainty it may be concluded that frequency

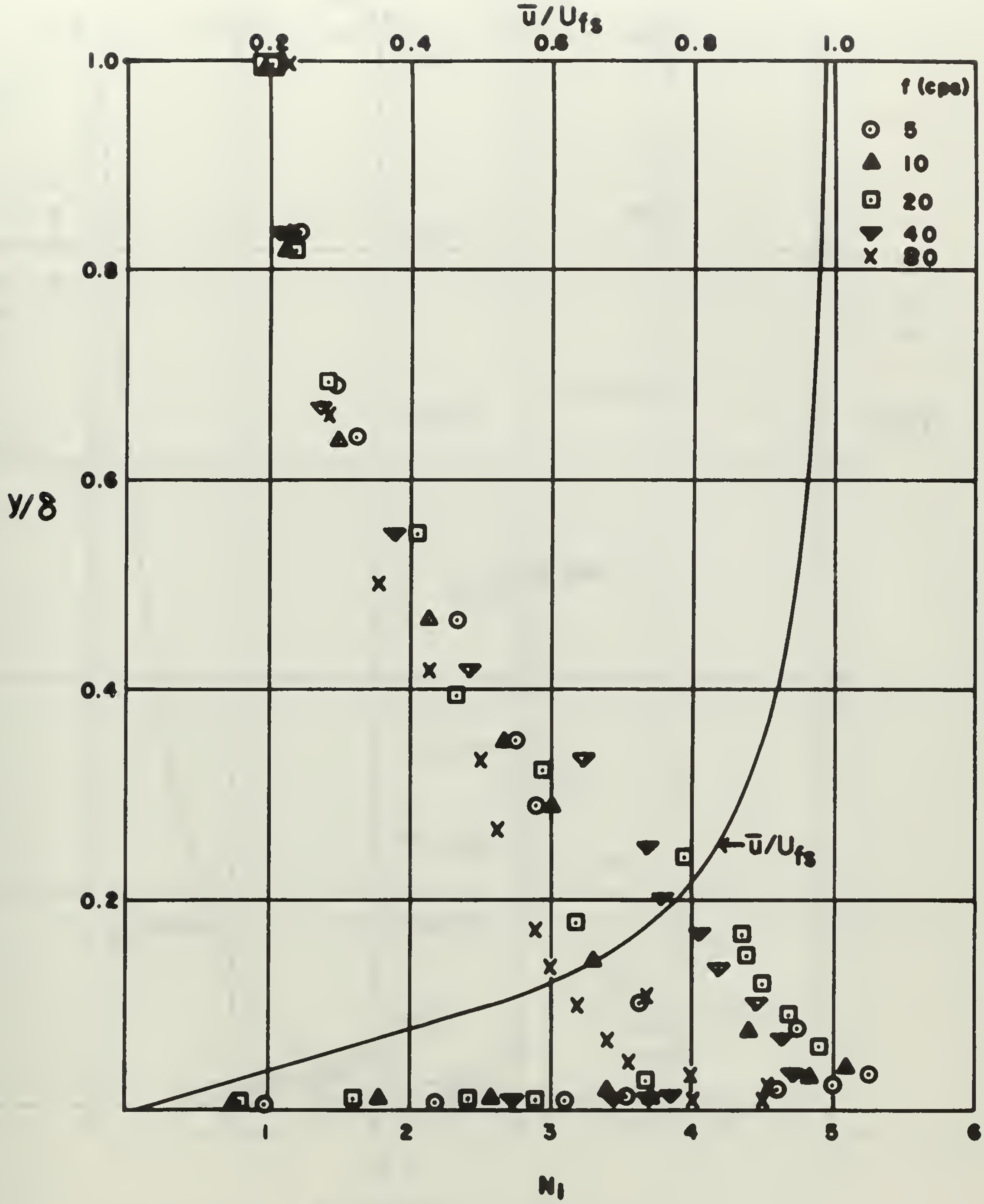

FIGURE II

DISTRIBUTION OF TURBULENT INTENSITIES

$N_e = .07$ $R_x = 1.5 \times 10^6$

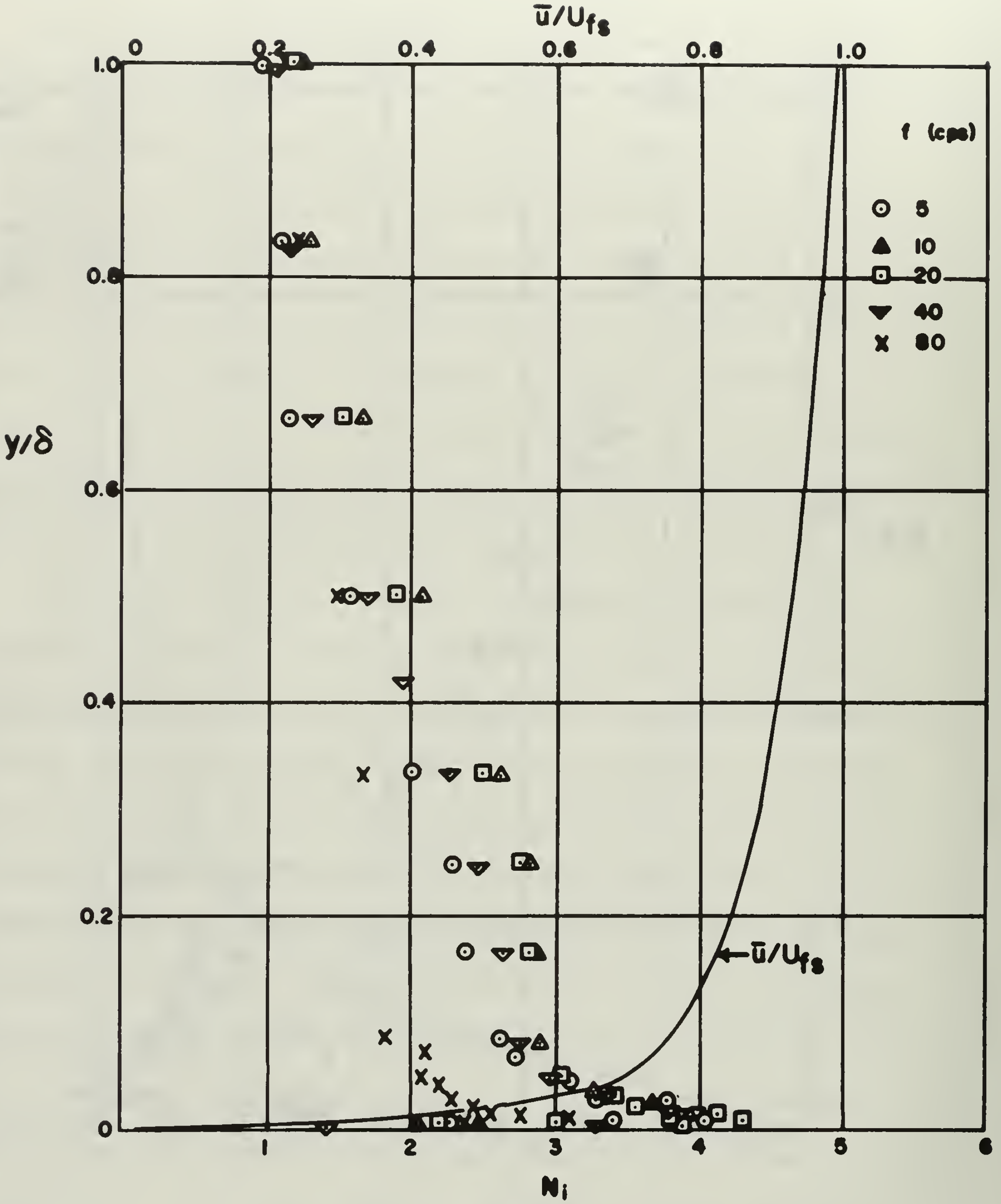

FIGURE 12

DISTRIBUTION OF TURBULENT INTENSITIES.

Na = .18 Rx = 1.5X10[6]

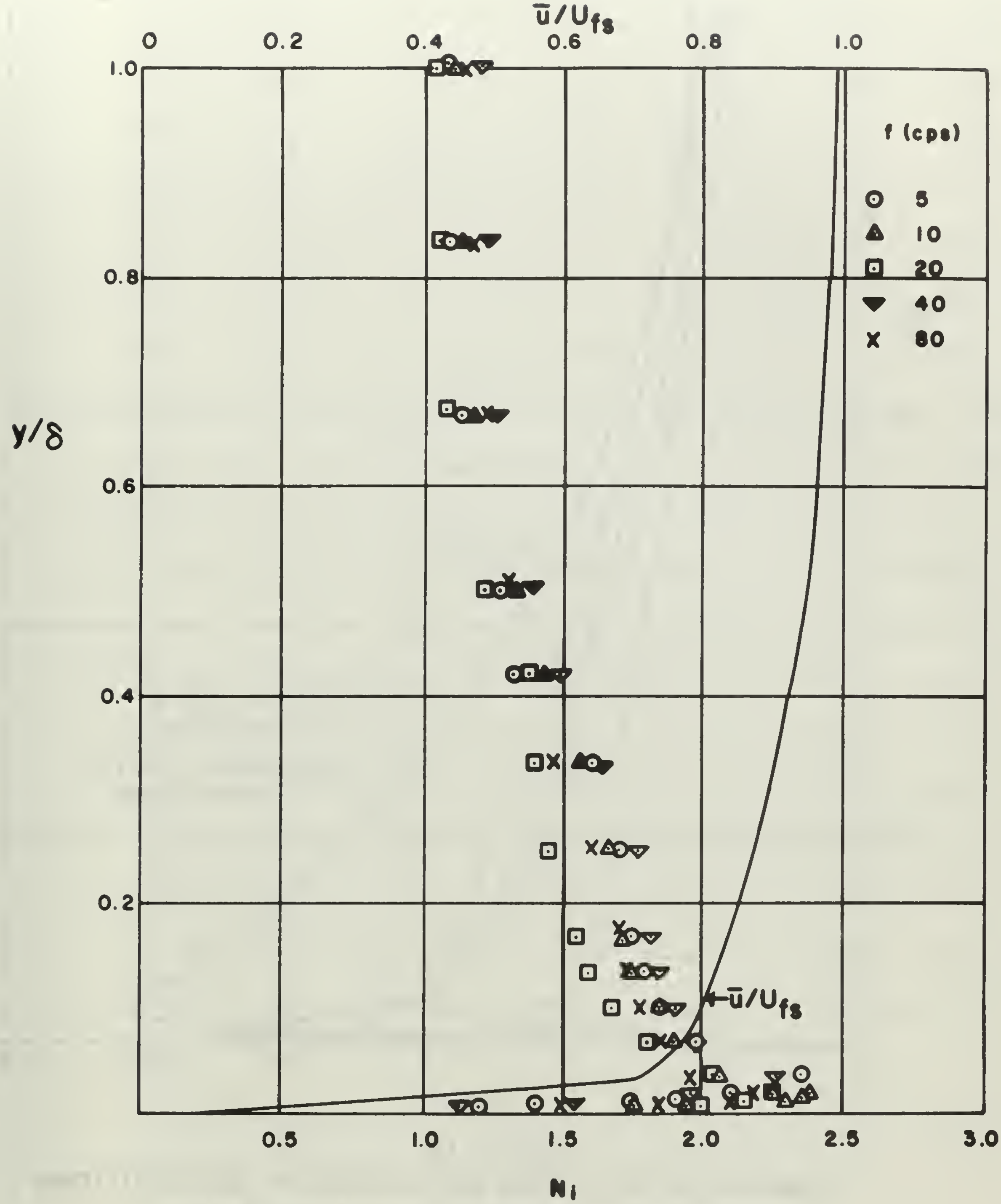

FIGURE 13

DISTRIBUTION OF TURBULENT INTENSITIES.

$N_a = .77$ R_x 1.5×10^6

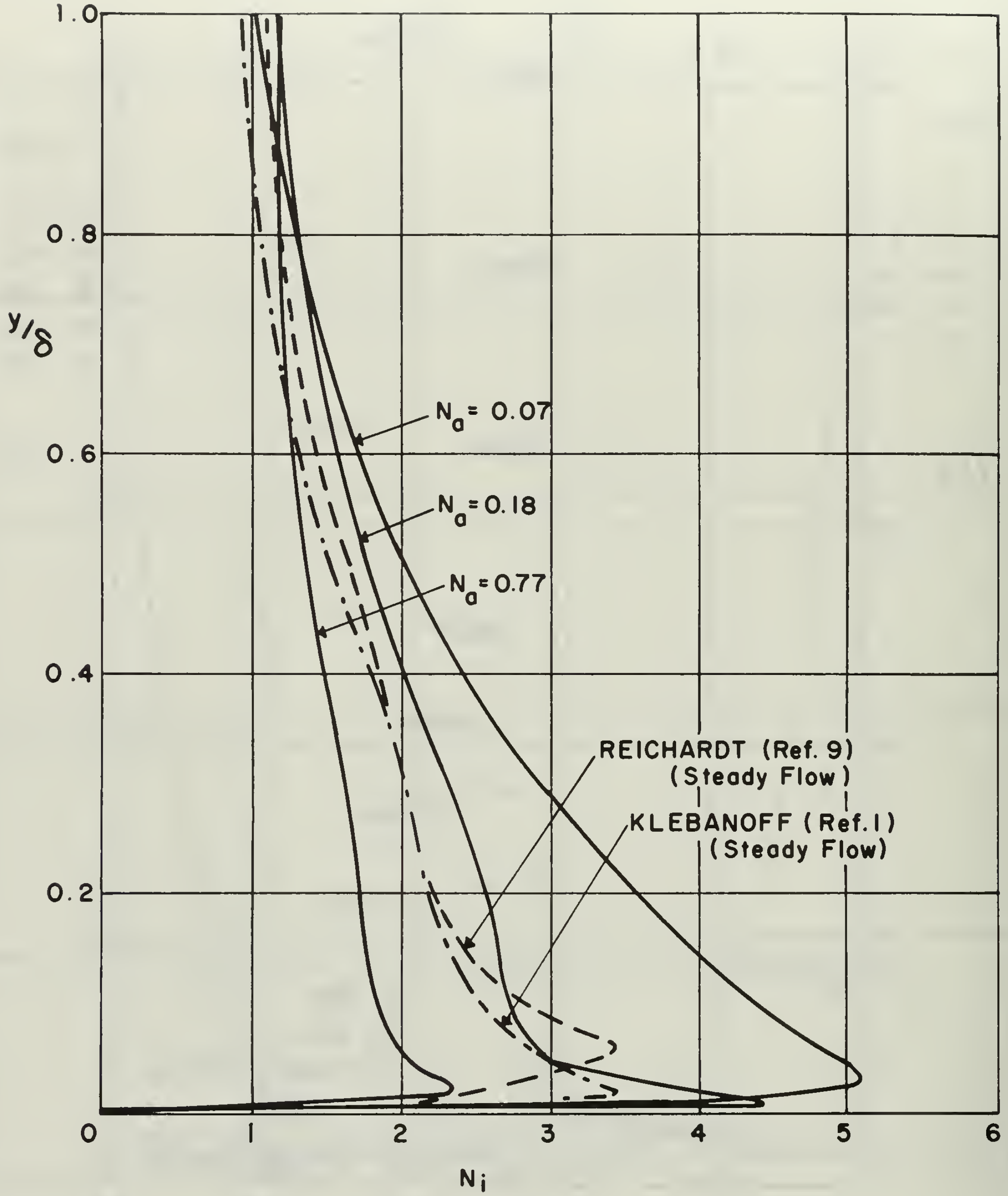

FIGURE 14
COMPARISON OF TURBULENT INTENSITY DISTRIBUTIONS
VARIOUS FLUCTUATION AMPLITUDES AND
STEADY FLOW RESULTS
$R_x = 1.5 \times 10^6$

and amplitude produce very little alteration in the turbulent intensity distribution in the turbulent boundary layer.

Figures 15, 16, and 17 are the oscilloscope trace photographs taken at four locations (y/δ = 1.0, 0.5, 0.02, and 0.005) in the boundary layer for each of the vertical traverses. An interesting phenomenon was observed in the boundary layer at low frequencies (for example, Figure 15 for f = 5.0 cps). The effect of these weak oscillations is to produce layers in the turbulent boundary layer in which turbulent bursts are seen. This is indicative of a late transition regime, that is, not a fully established turbulent boundary layer. This conclusion is born out by the measured velocity profile (Figure 11) as well as the data reported by Miller and Fejer (ref. 4).

Moreover, the hot wire traces are similar to those reported in the late transition regime by Miller and Fejer. This conclusion would also tend to explain part of the differences in results in Figure 14. The increased intensity observed for N_a = 0.07 might be attributed to a late transition regime rather than a fully turbulent regime.

Further work in this area might consider the effects on turbulent intensity profiles of a new velocity parameter involving the friction velocity. This approach might lead to stronger conclusions concerning the effects of freestream oscillations on turbulent intensity distribution.

The RMS value of velocity measured in this work was a superposition of residual turbulence on the lower frequency oscillations. A more accurate method of obtaining true turbulence might be pursued in a later project.

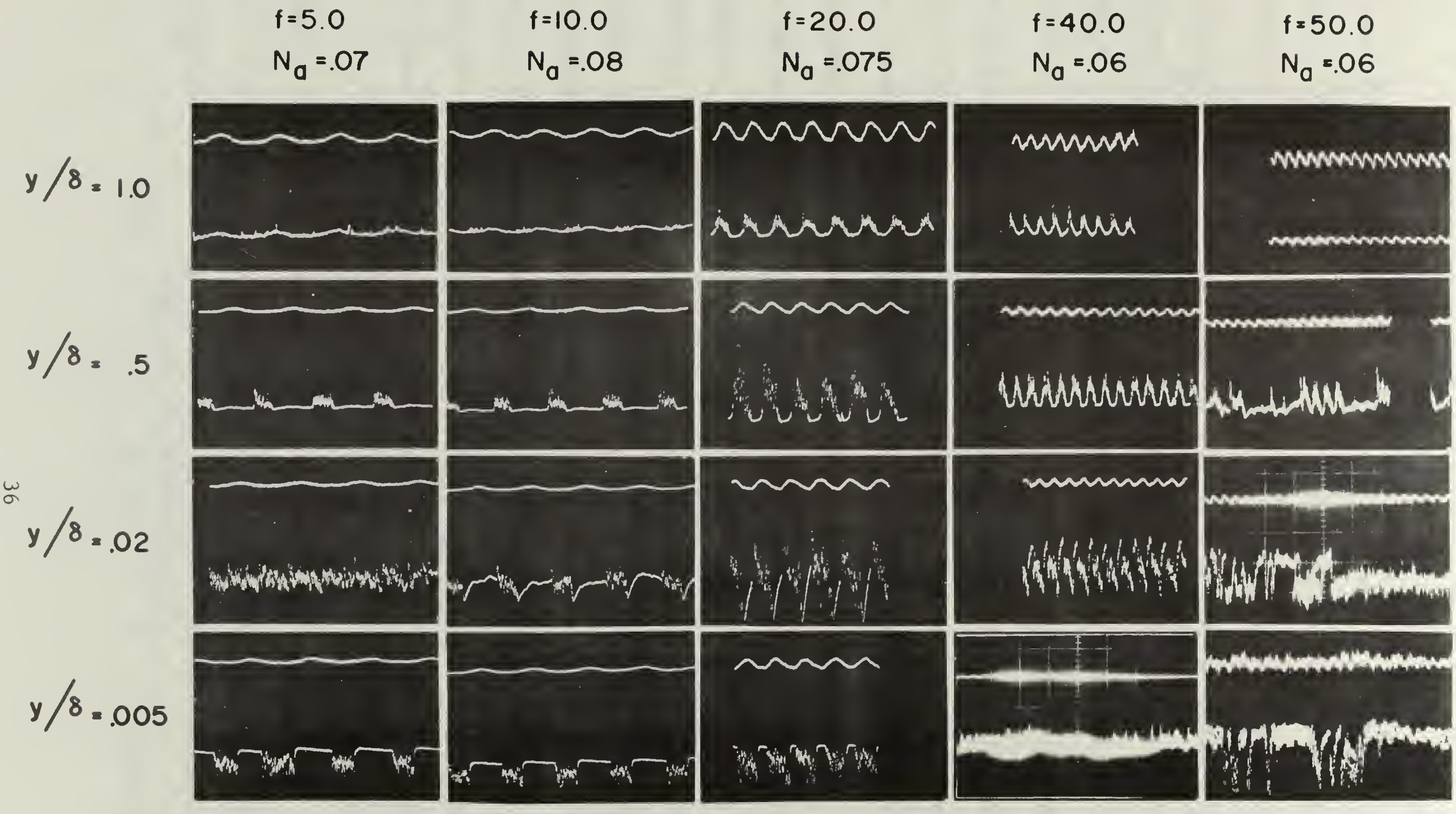

FIGURE 15

OSCILLOSCOPE TRACES OF TURBULENT INTENSITY IN THE FREESTREAM (UPPER BEAM) AND IN THE BOUNDARY LAYER (LOWER BEAM). 2" BLADES

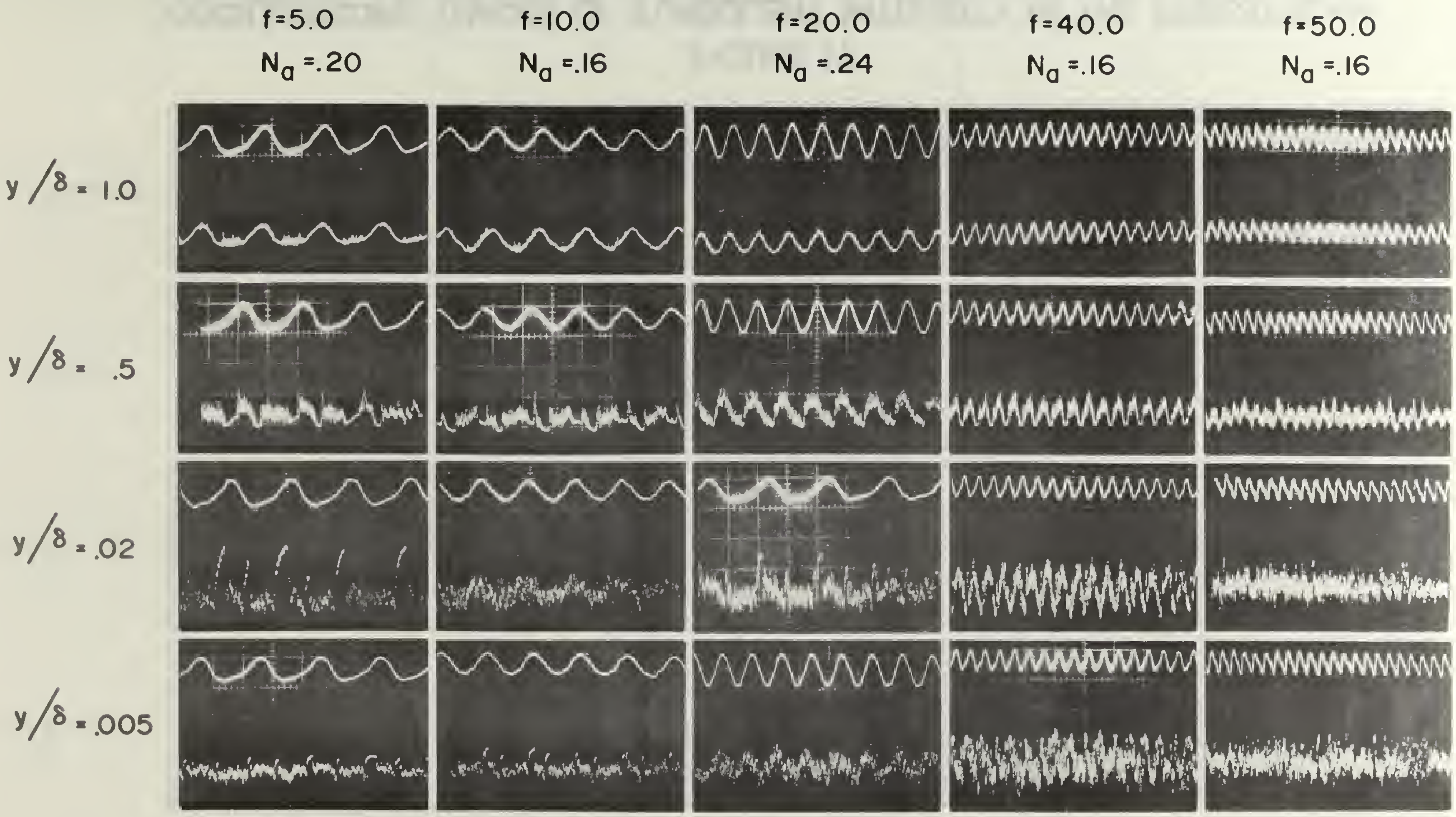

FIGURE 16

OSCILLOSCOPE TRACES OF TURBULENT INTENSITY IN THE FREESTREAM (UPPER BEAM) AND IN THE BOUNDARY LAYER (LOWER BEAM). 3" BLADES

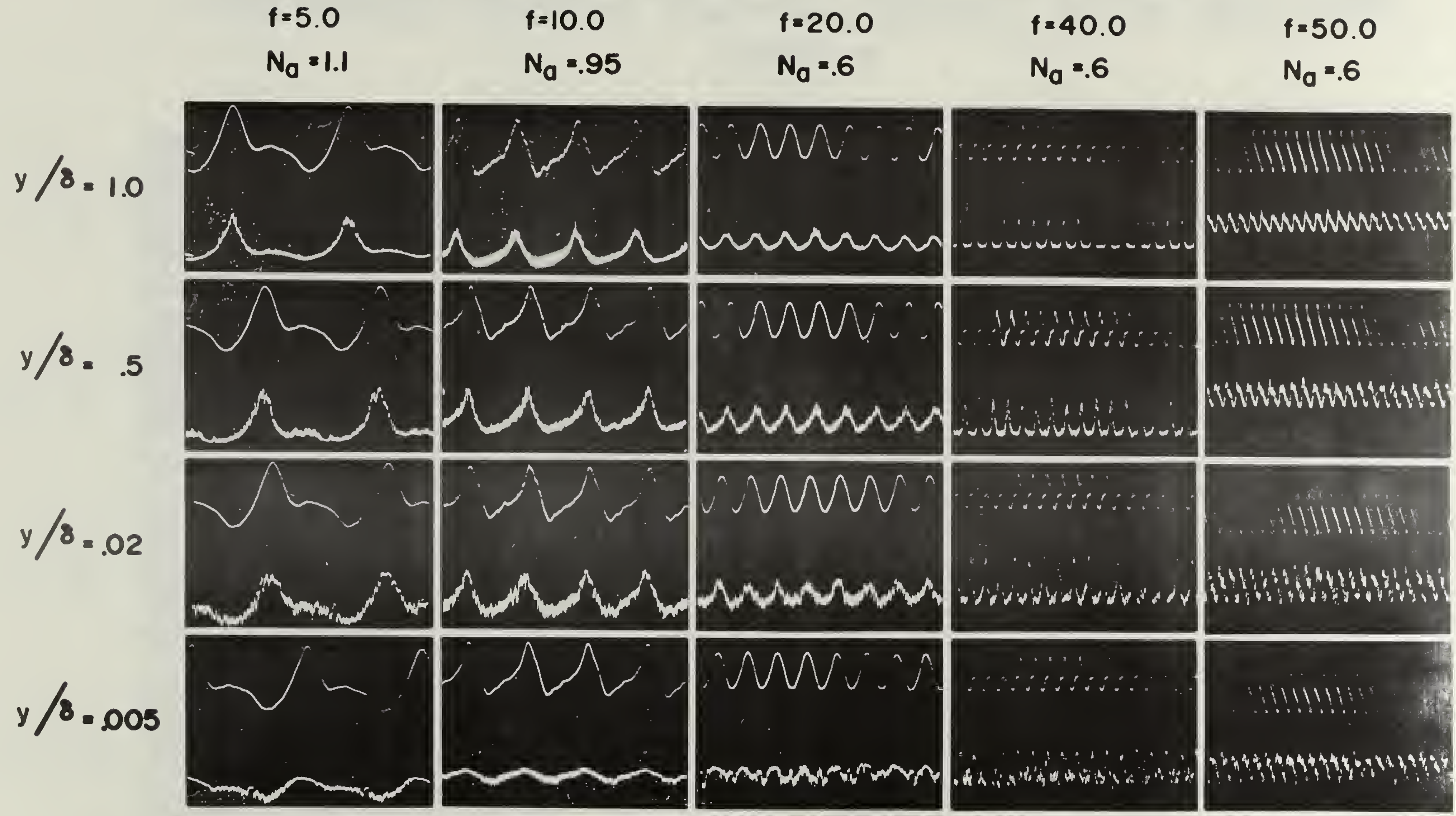

FIGURE 17

OSCILLOSCOPE TRACES OF TURBULENT INTENSITY IN THE FREESTREAM (UPPER BEAM) AND IN THE BOUNDARY LAYER (LOWER BEAM). 5" BLADES

4. Conclusions

The results of this investigation lead to the conclusion that, for the ranges of frequency and amplitude studied, the superposition of a fluctuating velocity component onto the mean flow does not substantially alter the turbulent intensity distribution in the turbulent boundary layer on a flat plate at zero incidence. This is in good agreement with the heat transfer measurements of Morrissey (ref. 5), who found only a 3 to 5 per cent increase in local Nusselt numbers in such flows.

One concludes that the relatively unchanged turbulent intensity profiles are indicative of relatively unchanged eddy diffusivity distributions, confirming the analysis of Karlsson (ref. 1), who found that the mean properties of the turbulent boundary layer were unaltered by the imposition of freestream oscillations.

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APPENDIX

TABLE III

EXPERIMENTAL RESULTS

Run Number 1	$N_a = 0.07$	f = 5.0 cps	$I_{fs} = 2.0\%$
y/δ	$\bar{u}/U_{fs}$	I	N_i
1.0	0.99	0.020	1.00
.821	.985	.024	1.20
.643	.975	.032	1.60
.554	.945	.036	1.80
.464	.930	.047	2.35
.349	.925	.055	2.75
.286	.895	.058	2.90
.178	.795	.065	3.25
.143	.695	.065	3.27
.107	.570	.074	3.70
.074	.390	.095	4.75
.037	.205	.105	5.25
.025	.160	.100	5.00
.021	.140	.093	4.65
.018	.110	.071	3.55
.014	.095	.063	3.17
.011	.061	.045	2.23
.007	.025	.019	0.97
0.004	0.005	0.001	0.05

TABLE III (continued)

Run Number 2	N_a = 0.08	f = 10.0 cps	I_{fs} = 2.0%
y/δ	$\bar{u}/U_{fs}$	I	N_i
1.0	0.990	0.020	1.00
.820	.980	.023	1.15
.640	.963	.030	1.50
.464	.940	.043	2.15
.349	.920	.054	2.70
.286	.882	.060	3.00
.178	.780	.064	3.17
.143	.680	.066	3.30
.110	.560	.073	3.65
.070	.400	.088	4.38
.036	.210	.103	5.12
.032	.195	.096	4.78
.029	.170	.093	4.63
.025	.150	.075	3.75
.021	.125	.072	3.60
.018	.105	.069	3.45
.014	.078	.052	2.60
.011	.050	.036	1.80
.007	.024	.017	0.85
0.004	0.005	0.002	0.10

TABLE III (continued)

Nun Number 3	N_a = 0.075	f = 20.0 cps	I_{fs} = 2.15%
y/δ	$\bar{u}/U_{fs}$	I	N_a
1.0	0.99	0.022	1.00
.820	.980	.026	1.20
.695	.975	.031	1.45
.545	.942	.044	2.05
.395	.905	.051	2.37
.318	.865	.063	2.95
.242	.830	.085	3.95
.166	.765	.093	4.35
.151	.750	.095	4.40
.121	.710	.097	4.50
.091	.625	.101	4.70
.061	.520	.106	4.92
.031	.345	.080	3.70
.015	.340	.063	2.92
.012	.150	.053	2.45
.009	.120	.034	1.60
.006	.030	.017	0.80
0.003	0.005	0.003	0.11

TABLE III (continued)

Run Number 4	N_a = 0.006	f = 40.0 cps	I_{fs} = 2.0%
y/δ	$\bar{u}/U_{fs}$	I	N_i
1.0	0.99	0.021	1.05
.833	.985	.023	1.15
.667	.980	.028	1.40
.500	.970	.039	1.95
.416	.955	.049	2.45
.332	.940	.065	3.25
.250	.925	.074	3.70
.200	.895	.076	3.80
.167	.865	.081	4.05
.133	.815	.084	4.20
.100	.740	.089	4.45
.067	.640	.093	4.65
.033	.545	.095	4.75
.017	.465	.078	3.90
.013	.375	.075	3.75
.010	.330	.070	3.50
.007	.305	.065	3.25
0.003	0.280	0.055	2.75

TABLE III (continued)

Run Number 5	N_a = 0.06	f = 80.0 cps	I_{fs} = 1.5%
y/δ	$\bar{u}/U_{fs}$	I	N_i
1.0	0.990	0.017	1.13
.833	.990	.018	1.20
.667	.985	.021	1.40
.500	.980	.027	1.82
.416	.965	.032	2.15
.332	.950	.037	2.50
.250	.940	.040	2.65
.167	.925	.044	2.90
.133	.885	.045	3.00
.100	.830	.048	3.20
.067	.790	.051	3.40
.050	.710	.053	3.55
.033	.590	.060	4.00
.017	.405	.069	4.55
.013	.400	.068	4.50
.010	.380	.064	4.25
0.005	0.300	0.060	4.00

TABLE III (continued)

Run Number 6	N_a = 0.16	f = 80.0 cps	I_{fs} = 5.45%
y/δ	$\bar{u}/U_{fs}$	I	N_i
1.0	0.990	0.060	1.10
.833	.960	.064	1.20
.667	.935	.080	1.47
.500	.920	.084	1.54
.333	.905	.092	1.68
.083	.875	.100	1.83
.067	.825	.114	2.10
.050	.780	.115	2.12
.040	.750	.120	2.20
.030	.740	.124	2.24
.025	.680	.134	2.46
.015	.645	.140	2.56
.012	.600	.150	2.76
.009	.510	.162	2.96
.005	.400	.168	3.08
.003	.290	.180	3.30
0.002	0.130	0.130	2.38

TABLE III (continued)

Run Number 7	N_a = 0.16	f = 40.0 cps	I_{fs} = 6.7%
y/δ	$\bar{u}/U_{fs}$	I	N_i
1.0	0.990	0.070	1.04
.833	.985	.078	1.16
.667	.975	.088	1.32
.500	.940	.104	1.70
.416	.925	.132	1.96
.333	.900	.152	2.28
.250	.880	.166	2.48
.167	.840	.176	2.64
.083	.825	.186	2.76
.050	.765	.200	3.00
.033	.735	.226	3.36
.017	.690	.252	3.76
.013	.665	.258	3.86
.010	.620	.268	4.00
.007	.550	.274	4.04
.005	.375	.222	3.32
.003	.295	.134	2.00
0.001	0.205	0.095	1.41

TABLE III (continued)

Run Number 8	N_a = 0.24	f = 20.0 cps	I_{fs} = 6.3%
y/δ	$\bar{u}/U_{fs}$	I	N_i
1.0	0.990	0.073	1.16
.833	.980	.081	1.28
.667	.960	.096	1.52
.500	.950	.120	1.90
.333	.925	.159	2.52
.250	.895	.174	2.76
.167	.875	.176	2.80
.083	.830	.180	2.78
.050	.780	.192	3.04
.033	.740	.201	3.34
.027	.700	.216	3.44
.020	.670	.226	3.60
.017	.615	.230	3.66
.013	.570	.240	3.80
.010	.490	.254	3.92
.007	.425	.252	3.90
.005	.325	.189	3.00
0.003	0.210	0.139	2.20

TABLE III (continued)

Run Number 9	$N_a = 0.16$	$f = 10.0$ cps	$I_{fs} = 4.6\%$
y/δ	$\bar{u}/U_{fs}$	I	N_i
1.0	0.990	0.056	1.22
.833	.975	.060	1.30
.667	.960	.076	1.65
.500	.930	.096	2.08
.333	.900	.122	2.64
.250	.880	.127	2.76
.167	.835	.131	2.84
.083	.770	.132	2.88
.050	.725	.134	2.92
.033	.675	.141	3.06
.027	.630	.150	3.26
.020	.580	.168	3.66
.017	.540	.188	4.08
.013	.490	.200	4.36
.010	.410	.180	3.90
.007	.325	.132	2.86
.005	.230	.110	2.40
0.003	0.210	0.104	2.06

TABLE III (continued)

Run Number 10	N_a = 0.20	f = 5.0 cps	I_{fs} = 5.5%
y/δ	$\bar{u}/U_{fs}$	I	N_i
1.0	0.990	0.055	1.00
.833	.985	.060	1.09
.667	.975	.064	1.16
.500	.950	.088	1.60
.333	.920	.110	2.00
.250	.880	.128	2.32
.167	.845	.130	2.36
.083	.760	.144	2.62
.067	.725	.150	2.72
.050	.667	.172	3.12
.033	.625	.190	3.44
.027	.580	.200	3.64
.020	.550	.212	3.86
.013	.470	.204	3.76
.007	.300	.190	3.44
0.003	0.175	0.126	2.28

TABLE III (continued)

Run Number 11	N_a = 1.10	f = 5.0 cps	I_{fs} = 25.0%
y/δ	$\bar{u}/U_{fs}$	I	N_i
1.0	0.990	0.270	1.08
.833	.980	.275	1.10
.667	.970	.290	1.15
.500	.945	.320	1.29
.416	.915	.340	1.37
.333	.890	.410	1.61
.250	.780	.425	1.70
.167	.750	.435	1.74
.133	.675	.450	1.79
.100	.630	.462	1.85
.067	.550	.491	1.97
.033	.485	.590	2.36
.017	.405	.530	2.11
.013	.310	.470	1.92
.010	.225	.438	1.75
.007	.150	.350	1.41
0.003	0.100	0.305	1.22

TABLE III (continued)

Run Number 12	$N_a = 0.95$	f = 10.0 cps	$I_{fs} = 24.0\%$
y/δ	$\bar{u}/U_{fs}$	I	N_i
1.0	0.990	0.270	1.12
.833	.990	.272	1.13
.667	.980	.285	1.18
.500	.965	.310	1.30
.416	.950	.340	1.42
.333	.905	.375	1.57
.250	.870	.400	1.67
.167	.830	.410	1.71
.133	.800	.420	1.75
.100	.720	.430	1.80
.067	.615	.455	1.90
.033	.560	.500	2.07
.017	.470	.540	2.25
.013	.410	.571	2.38
.010	.300	.570	2.37
.007	.270	.550	2.28
0.003	0.200	0.420	1.75

TABLE III (continued)

Run Number 13	N_a = 0.60	f = 20.0 cps	I_{fs} = 20.5%
y/δ	$\bar{u}/U_{fs}$	I	N_i
1.0	0.990	0.214	1.04
.833	.985	.218	1.06
.667	.970	.225	1.10
.500	.940	.255	1.25
.416	.920	.280	1.38
.333	.865	.290	1.42
.250	.805	.300	1.46
.167	.780	.320	1.55
.133	.730	.328	1.60
.100	.680	.345	1.68
.068	.620	.370	1.81
.033	.580	.420	2.05
.017	.420	.460	2.25
.013	.330	.440	2.15
.010	.250	.410	2.00
.007	.190	.400	1.95
0.003	0.110	0.360	1.75

TABLE III (continued)

Run Number 14	N_a = 0.60	f = 40.0 cps	I_{fs} = 18.8%
y/δ	$\bar{u}/U_{fs}$	I	N_i
1.0	0.990	0.225	1.20
.833	.985	.228	1.21
.667	.980	.235	1.25
.500	.960	.260	1.38
.416	.915	.278	1.47
.333	.875	.305	1.63
.250	.810	.330	1.76
.167	.770	.340	1.81
.133	.760	.345	1.83
.100	.700	.355	1.88
.067	.630	.370	1.97
.033	.600	.425	2.26
.017	.540	.355	1.90
.013	.480	.330	1.75
.010	.400	.290	1.55
.007	.320	.265	1.40
0.003	0.200	0.216	1.15

TABLE III (continued)

Run Number 15	N_a = 0.60	f = 80 cps	I_{fs} = 19.8%
y/δ	$\bar{u}/U_{fs}$	I	N_i
1.0	0.990	0.230	1.16
.833	.985	.235	1.18
.667	.970	.245	1.23
.500	.950	.260	1.31
.416	.925	.275	1.38
.333	.880	.295	1.48
.250	.810	.320	1.62
.167	.760	.340	1.71
.133	.745	.345	1.74
.100	.650	.350	1.77
.067	.615	.362	1.83
.033	.490	.395	1.99
.017	.440	.430	2.17
.013	.420	.415	2.10
.010	.385	.365	1.85
.007	.320	.347	1.75
0.003	0.215	0.297	1.50

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13. ABSTRACT

The effect of oscillating flow on the turbulent intensity distribution in the turbulent boundary layer on a flat plate was investigated experimentally.

A wind tunnel incorporating a set of rotating shutter blades downstream of the test section was used to create oscillating flow with amplitude variations from 6 to 110 per cent of mean velocity and frequencies ranging from 5 to 80 cycles per second at a local Reynolds number of 1.5×10^6. A vertical traverse of the turbulent boundary layer was conducted with a hot wire anemometer, and the mean velocity profile and the turbulent intensity distribution were recorded.

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Turbulence Boundary Layer Turbulent Intensity Distribution Unsteady Flow Oscillating Flow Experimental Flat Plate						